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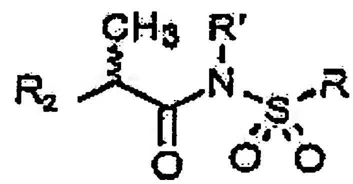
USE OF N-(2-ARYL-PROPIONYL)-SULFONAMIDES FOR THE TREATMENT OF SPINAL CORD INJURY

The present invention concerns the use of N-(2-aryl-propionyl)-sulfonamides of general formula (**I**):



(I)

in which

R_2 is an aryl group,

R is a straight or branched C_1-C_6-alkyl, trifluoromethyl, cyclohexyl, o-tolyl, 3-pyridyl, 2-pyridyl-ethyl, p-cyano-phenylmethyl, p-aminophenylmethyl, 3-cyano-1-propyl, 4-aminobutyl group, an alkoxyethylene CH_3-$(CH_2)_{ni}$-$(OCH_2CH_2)_{mi}$- group in which n_i is zero or 1 and m_i is an integer 1 to 3, or a P_1P_2N-CH_2-CH_2- group in which P_1 and P_2 are independently H, C_1-C_3- alkyl, benzyloxy-carbonyl, α-, β- or α-pyridocarbonyl, carboxycarbonyl or carbalkoxycarbonyl, or P_1 and P_2, when joined to the N atom which they are linked to, form a phthalimido, piperidino, morpholino residue;

R' is H or straight or branched C_1-C_3-alkyl, preferably hydrogen, for the preparation of a medicament for the treatment of spinal cord injury.

Background of the invention

Spinal cord injury (SCI) is one of the most frustrating conditions in neurology and medicine. The vast majority of SCI patients are young, and most survivors of significant injury face the prospects of limited recovery and permanent disability. The incidence of new SCI case is high, exceeding

12.000 new cases per year of paraplegia or quadriplegia in the United States (Sekhon L. et al. *Spine* 26, S2-S12, 2001). Yet with improved management, the mortality rate of SCI has steadily fallen. As a result, the prevalence of patients disabled by SCI now approximates 200.000 in the Unites States alone. The need for effective acute intervention, both to limit the numbers of permanently impaired patients and to give real hope to the newly injured, is particularly felt.

Current treatment of SCI is limited to high-dose glucocorticoid therapy, which is useful only when administered within hours of injury (Bracken M.B. et al. *The New England Journal of Medicine* 322, 1405-1411, 1990). The mechanisms by which the steroids exert their moderately beneficial effects remain unclear, though they are generally attributed to the protective effects on lipid peroxidation. Indeed, methylprednisolone suppresses the breakdown of membrane and neurofilament by inhibiting lipid peroxidation in injured spinal cord (Braughler J.M. et al. *J. Neurosurg* 67, 102-105, 1987). Yet, despite the fundamental inadequacy, high-dose glucocorticoid treatment has remained the only available therapy for SCI.

The pathogenesis of SCI is now known to involve cytokines, particularly Tumor Necrosis Factor (TNF), the expression of which contribute to neuronal death after SCI (Beattie M.S. et al. *Progress in Brain Research* 137, 37-47, 2002) and leukocytes infiltration. Indeed, SCI results in both primary injury, characterized by disruption of neural and vascular structure, and a cascade of secondary processes that collectively lead to additional loss of tissue. Post-traumatic inflammation, characterized by the accumulation of activated microglia and leukocytes, is thought to contribute to secondary pathogenesis (Mautes A.E.M. et al. *Physical Therapy* 80, 673-687, 2000). Strategies aimed at blocking neutrophil or macrophages influx and at inhibition of phagocytic and secretory activity of macrophages in the injured

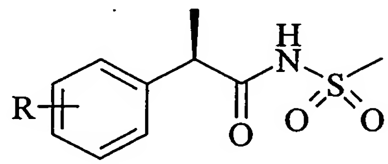
spinal cord have resulted in neuroprotection and improved locomotory function (Giulian D. et al. *Ann. Neurol.* 27, 33-42,1990; Taoka Y. et al. *Neuroscience* 79, 1177-1182, 1997).

Indeed, according to the available knowledge, the selective inhibition of interleukin-8 (CXCL8)- induced chemotaxis is not a sufficient condition for the protection of SCI. In fact, the scientific literature identified numerous factors involved in the etiology of the SCI, among which factors, CXCL8 does not certainly appear as one of the most important: for example Taoka Y. et al. (*Journal of Neurotrauma* 18, 533-543, 2001) report that leukocytopenia and inhibition of leukocyte recruitment by administration of an anti-P-selectin monoclonal antibody, an aspecific blocker of leukocyte adhesion, significantly reduced motor disturbances observed following SCI. In addition, recent research has shown elevated plasma levels of inflammatory mediators, including interleukin-2, interleukin-6, the soluble intereleukin-2 receptor, and intercellular adhesion molecule-1 (ICAM-1) in patients with long-standing SCI, as possible pathogenetic factors of the delay in the functional recovery (Segal J.L. et al. *Arch. Phys. Med. Rehabil.* 78, 44-47, 1997). US 2001/0016195 discloses the treatment of a number of different pathologies, including SCI, by means of antagonists, e.g. antibodies, of various cytokines including IL-1, IL-6 and IL-8. This document does not anyhow connect SCI with IL-8 inhibition. It follows that, from the literature data, an aspecific inhibitor of the inflammatory response or, at least, of leukocyte recruitment would appear necessary for the inhibition of SCI.

The N-(2-aryl-propionyl)-sulfonamides of general formula (I) above are disclosed in EP 1123276 and in European Patent Application EP 04101202.2. The sulfonamides described therein are reported to be useful, for example, in the prevention and treatment of tissue damage due to exacerbated recruitment of polymorphonuclear neutrophils (PMN leukocytes) at the inflammatory sites.

Description of the invention

It has now surprisingly been found that said sulfonamides of formula **(I)**, and particularly the sulfonamides of formula **(Ia)**

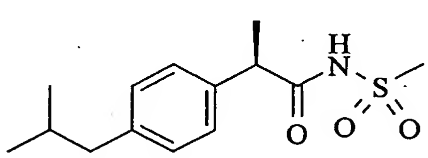


(Ia)

wherein R represents one to three substituents, which are the same or different, selected from hydrogen, halogen atoms, C_1-C_4-alkyl, C_1-C_4-alkoxy, hydroxy, C_1-C_7-acyloxy, cyano, nitro, amino, C_1-C_3-acylamino, halo C_1-C_3-alkyl, halo C_1-C_3-alkoxy, benzoyl, 4-(2-methyl-propyl)-phenyl, 3-phenoxy-phenyl, 2-[4-(1-oxo-2-isoindolinyl)phenyl], 5-benzoyl-thien-2-yl, 4-thienoyl-phenyl, C_1-C_2-halogenoalkylsulphonyloxy, are effective in the protection from functional injury of SCI.

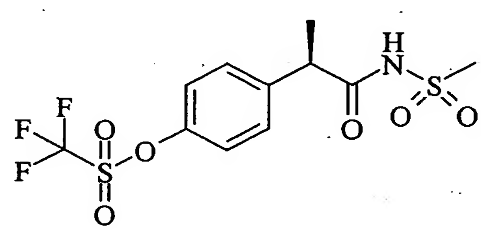
R, in the compounds of formula **(Ia)**, preferably represents hydrogen, 4-isobutyl, 3-benzoyl, 4-trifluoromethanesulphonyloxy.

The protection from functional injury of SCI has been demonstrated in an experimental model in rats, disclosed in detail hereinafter, using two representative compounds of formula **(I)**, namely the compound of formula **(II)** and its lysine salt (L-lysine or DL-lysine), and the compound of formula **(III)**. Both compounds were found very active in this in vivo model.



(II)

(R)-ibuprofen methanesulfonamide



(III)

R-2-[(4'-trifluoromethanesulphonyloxy) phenyl]-N-methanesulfonyl propionamide

Compound of formula (**II**) and compound of formula (**III**) also reduced tissue injury, evaluated as extension of post-traumatic cavity, oligodendrocytes apoptosis and leukocyte infiltration.

The invention is illustrated in the following Example.

<u>EXAMPLE</u>

Adult Sprague-Dawley rats (females) weighing 240-260 g were maintained in the animal facilities under standard housing conditions (22 ± 2°C, 65% humidity, artificial light from 06.00-20.00 h). A standard dry diet and water were available *ad libitum*.

SCI in the rat was performed as previously reported (Gorio A. et al. *Proc. Natl. Acad. Sci. USA* 99, 9450-9455, 2002). The lesioning apparatus is computer controlled and free of the influence of gravity force. The force applied was 1N per 1 second.

Recovery from hind limb disability was evaluated by means of "free locomotion test" performed 24 hours, 4, 7, 11, 15, 19 and 27 days after SCI.

The "free locomotion test" allows the detection of feet positioning, and joint rotation. The quality of functional recovery is quantitatively expressed according to the "BBB scale" developed at the Ohio University. Such a test allows the quantification of rat hind limb free locomotion deficits by observing their movements in an open space free of obstacles:

0- Lesioned rat cannot move either limbs

1- Small movement of a joint (heap or knee)

From 2 to 6- Movement in progressive extension of the 3 joints

7- Good movement of the 3 joints

8- Animals walk without plantar support of the weight

From 9 to 11- Animals walk from occasionally to progressively frequent with plantar support of the weight.

12- Occasional coordination of hind limbs and forelimbs during walk

From 13 to 14- Progressive coordination with the forelimbs.

15- Consistent plantar support of weight and coordination during walk; occasional movement of fingers during advancement.

From 16 to 18- Progressive tendency to finger movements; during walk the foot is predominantly in parallel position to the body.

19- The foot position is correctly parallel to the body, and the tail is maintained low during walk.

20- Wobbling lateral and unstable locomotion

21- Normal condition

Apoptosis of oligodendrocytes was determined at the level of the gracilis and cuneatus fascicle (3 mm rostrally from the site of contusion injury) 28 days after SCI using the terminal deoxynucleotidyltransferase-mediated dUTP and labeling (TUNEL) methodology.

Leukocyte infiltration was quantitatively estimated by CD68 positive cells 1 and 7 days after SCI.

Extension of post-traumatic cavity was performed by classical histological techniques 28 days after SCI.

The following experimental groups of animals were considered:

Group 1 (n=28) rats treated with saline solution after SCI

Group 2 (n=28) rats treated with compound of formula **(II)** after SCI

Group 3 (n=28) rats treated with compound of formula **(III)** after SCI

Animals were treated with saline or compound of formula **(II)** (15 mg/kg) by i.v. injection within 30 minutes after SCI, then s.c. every 2 hours in the following 6 hours. The following days the animals were treated s.c. at 8 am and 5 pm until the 7^{th} day after SCI. Animals were treated with compound of formula **(III)** (8 mg/kg) by i.v. injection within 30 minutes after SCI, then s.c. 24 hours after SCI. The following days the animals were treated s.c. every 36 hours until the 7^{th} day after SCI.

In addition the efficacy of compound of formula (**II**) was evaluated after subcutaneous (s.c.) continuous infusion treatment on recovery from hind limb disability. The pump was implanted subcutaneously in the rat. A small incision was made in the skin between the scapulae and, using a haemostat, a pocket was formed by spreading apart the s.c. connective tissues. The pump was inserted into the pocket with the flow moderator pointing away from the incision. The skin incision was closed with wound clips. The quality of functional recovery was evaluated 24 hours, 4, 7, 11 14, 24 and 27 days after SCI. The following experimental groups of animals were considered:

Group 1 (n=8) rats treated with saline solution by s.c. infusion starting within 30 minutes after SCI

Group 2 (n=8) rats treated with compound of formula (**II**) at an infusion rate of 2.5 mg/kg/h starting within 30 minutes after SCI

Group 3 (n=8) rats treated with compound of formula (**II**) at an infusion rate of 5 mg/kg/h starting within 30 minutes after SCI

Group 4 (n=8) rats treated with compound of formula (**II**) at an infusion rate of 10 mg/kg/h starting within 30 minutes after SCI

Group 5 (n=8) rats treated with compound of formula (**II**) at an infusion rate of 10 mg/kg/h starting from 24 hours after SCI

Animals were treated with saline or compound of formula (**II**) by s.c. infusion until the 7^{th} day after SCI.

Data were analyzed by ANOVA followed by Dunnett's *t* test. Statistical significance was accepted at $P<0.05$.

<u>Results</u>

The effect of compound of formula (**II**) and compound of formula (**III**) on functional recovery (motor score), quantitatively expressed according to the "BBB scale", was evaluated at different times after SCI. Figure (1) shows the effect of (R)-ibuprofen methanesulfonamide, and figure (2) shows the effect of R-2-[(4'-

trifluoromethanesulphonyloxy)phenyl]-N-methanesulfonyl propionamide. All animals subjected to SCI were profoundly affected immediately after injury (motor score 0 for all groups) and significant recovery was not evident in vehicle (saline) treated group until the 7th day after SCI. Treatment with compound of formula **(II)** and compound of formula **(III)** significantly promoted functional hind limb recovery after SCI. The recovery was progressive, being the most effective period between the 4th and the 11th day after SCI.

Immunohistologic evaluation of leukocyte infiltration was evaluated 1 day and 7 days after SCI. As shown in Table 1, compound of formula **(II)** dramatically reduced leukocyte infiltration (80% of inhibition) at 24 hours and 7 days after SCI. A similar inhibition of leukocyte recruitment was also observed in rats treated with compound of formula **(III)** (data not shown).

It is well known that apoptosis of oligodendrocytes is a crucial event during the early stages after traumatic lesion of the spinal cord, and that the extend of neurological recovery is also dependent on how such process can be counteracted or attenuated. Oligodendrocyte death causes demyelination of the axons spared by the lesion, thus causing loss of the ability to conduct the electrical impulse across the lesion site. The pharmacological attenuation of oligodendrocyte apoptosis is thus a primary target of any pharmacological treatment aiming at promoting recovery after SCI. As shown in Table 2, treatment with compound of formula **(II)** and compound of formula **(III)** blocked oligodendrocyte apoptosis determined 28 days after SCI [85% and 65% of inhibition after treatment of rats with (R)-ibuprofen methanesulfonamide and R-2-[(4'-trifluoromethanesulphonyloxy)phenyl]-N-methanesulfonyl propionamide, respectively].

Finally, it was investigated the effect of compound of formula **(II)** and compound of formula **(III)** on tissue damage induced by SCI. As shown in Table 3, treatment with compounds described above significantly reduced

tissue damage at the site of the lesion and the extension of post-traumatic cavity 28 days after SCI.

Next we evaluated the efficacy of compound of formula (**II**) after s.c. continuous infusion on functional recovery. As shown in figure (3) treatment with compound of formula (**II**) at an infusion rate of 5 mg/kg/h or 10 mg/kg/h significantly promoted functional hind limb recovery after SCI evaluated until 14 days after SCI. In addition, compound of formula (**II**) administered by s.c. infusion at an infusion rate of 10 mg/kg/h significantly promoted functional hind limb recovery even if compound administration started from 24 hours after SCI. As shown in figure (4) the recovery was progressive being the most effective period between the 7th and the 24th day after SCI.

In conclusion, data reported above clearly show how compound of formula (**II**) and compound of formula (**III**) can be advantageously used in medical practice in the promotion of functional recovery after SCI.

Table 1. Number of infiltrated leukocytes (mean ± SE; n=8)

Time from SCI	**1 day**		**7 days**	
	Saline	Formula (**II**)	Saline	Formula (**II**)
Epicenter	125±36	24±3***	235±54	19±3***
Periphery	56±13	3±1***	99±32	4±2***

***P<0.001 (R)-ibuprofen methanesulfonamide treated animals vs saline treated animals

Table 2. Number of oligodendrocyte apoptotic nuclei (mean ± SE; n=12)

Treatment	
Saline	14.9±2
(R)-ibuprofen methanesulfonamide	2.1±1.2*
R-2-[(4'-trifluoromethanesulphonyloxy)phenyl]-N-methanesulfonyl propionamide	5.2±3.8*

*P<0.05 and ***P<0.001 drug treated animals vs saline treated animals

Table 3. Percentage of spared tissue at lesion site (mean ± SE; n=12)

Treatment	Lesion Epicenter	Cavity Volume
Saline	39.8±3.9	46.6±3.1
(R)-ibuprofen methanesulfonamide	48.9±3.0**	58.2±2.9**
R-2-[(4'-trifluoromethanesulphonyloxy)phenyl]-N-methanesulfonyl propionamide	49.7±4.2**	60.4±4.3**

**P<0.01 drug treated animals vs saline treated animals

For the considered therapeutical purposes, suitable pharmaceutical compositions may be prepared using conventional techniques and excipients such as those described in "Remington's Pharmaceutical Sciences Handbook" Mack Publishing Co., New York, 18th Ed., 1990.

The compositions of the invention will preferably be administered intramuscularly, intravenously, as bolus, in view of the urgency character of the pathology to be treated, even though other administration routes cannot be excluded, for instance the oral route.

The average daily dosage will depend on various factors such as severity of the disease and conditions of the patient (age, sex and weight). The dose will generally vary from 1 or a few mg to 1500 mg of the compounds daily, optionally subdivided in multiple administrations. Higher dosages can also be administered thanks to the low toxicity of the compounds of the invention, even for long-term treatments.